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PSYCHOLOGICAL CONSEQUENCES AND PILOT "SITUATIONAL AWARENESS" SURVEY

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1. INTRODUCTION

The technological design and developments already applied to a number of aircraft, which represent the basis of tomorrow's aircraft, tend to change the tasks performed by pilots. Since the 80's, automation and computerization have invaded cockpits, leading to a change in the role of pilots. Whereas pilots used to need competencies directed towards handling and navigating the aircraft, what is now increasingly required of them is the ability to manage complex systems. With the arrival of new concepts like supermaneuverability and superagility, it seems extremely important to try and understand the psychological consequences these concepts will have on pilots. Enabling new types of operation, supermaneuverability and superagility alter existing tasks and will probably create new ones, which will have their own psychological constraints. What makes these constraints different from those existing on present aircraft, and what consequences could they have on pilot performance? These two questions can be addressed by two preliminary comments:

- As of today, supermaneuverability and superagility are still extremely novel concepts. Various "prototype" aircraft point to the developments, which will eventually make these concepts a reality in the near future, but there still is no such thing as "real" operational experience. The difficulty in accurately studying the consequences these future aircraft will have on pilots, lies in trying to define the exact role the pilot will be asked to play aboard.
- The psychological consequences studied in this chapter will be limited to the consequences borne by the pilot in terms of taking and processing information. This chapter does not take into account psychological aspects based on personality or motivation.

2. EXPERIENCE ON CURRENT FIGHTER AIRCRAFT

Determining the psychological consequences on crews of flying agile aircraft is not an easy task, because of the lack of operational feedback regarding missions performed with these aircraft. The only way to envisage potential psychological consequences is to transfer the experience acquired on agile aircraft prototypes and on last generation combat aircraft to the operational situations these future agile aircraft are expected to meet.

To this end, the Working Group carried out a questionnaire survey with pilots of last generation combat aircraft flying in the Air Forces represented in the working group. The questionnaire was developed to address the following topics:

- Physiological constraints and psychological consequences,
- Cognitive constraints,
- Situational awareness and human performance,
- Aid systems,
- Crew training and practice.

The 15 question questionnaire was anonymous and made up of open and closed questions. The questionnaire is in Annexe 1. Twenty-nine pilots, representing 5 countries answered it:

- 3 pilots from Germany,
- 12 pilots from Sweden,
- 5 pilots from the Netherlands,
- 1 pilot from the US,
- 8 pilots from France.

These pilots flew last generation high performance aircraft, equipped with the latest weapons, navigation, communication and interface systems. These 29 pilots gave feedback on the following aircraft:

- Falcon 15,
- Falcon 16,
- Falcon 18,
- MiG 29,
- JAS 39,
- Mirage 2000 C-RDI, and
- Mirage 2000-5.

All pilots had an extensive aeronautic background, with an average flying time of 2,490 hours (standard deviation of 1,080 hours).

Questionnaire answers were processed by content analysis to draw out major trends. Given the sample polled, a qualitative analysis was more relevant than a quantitative one. This sample is not representative of the crew population flying last generation aircraft from NATO countries. Furthermore, for strict statistical purposes, the specificities of each aircraft

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(combination of aerodynamic capacities, on-board systems and interfaces), as well as pilot experience should be taken into account.

3. PHYSIOLOGICAL CONSTRAINTS AND PSYCHOLOGICAL CONSEQUENCES

3.1. Questionnaire results

The connection between cognitive and physiological constraints caused by load factors clearly appears in the answers to the questionnaire. This dimension is taken into account when assessing the mental effort required, since Gz acceleration has a direct impact on the pilot's mental resources. Acceleration impacts information processing at three levels:

- Part of the attention potential is mobilized by the mere activity of flying, to reach and maintain a high level load factor,
- Another large part of the attention potential is earmarked to off setting the physiological consequences of acceleration: applying anti-G maneuvers and having a proper body position in the cockpit,
- The field of vision is reduced because of the limitations in possible head movements and the physical consequences of acceleration on visual functions (restricted field of vision, greyout, etc.). Pilots only maintain central vision.

The crew is then forced to allocate the remaining resources to manage parameters essential to survival, to the detriment of weapons management, which inevitably becomes simplified.

Gy acceleration was not mentioned by pilots as penalizing in close combat situations.

3.2. Data from literature

Supermaneuverability refers to the unusual flight trajectories presently capable by high performance fighter aircraft (1). The trajectories illustrating supermaneuverability show that stress is mainly experienced by the pilot in terms of rotational and linear accelerations. These maneuvers are usually performed at low or medium altitude, and at low speed, under 450 kts, generally in a range between 70 and 265 kts. Vectorial thrust allows for pitch and yaw in ways impossible with more traditional aircraft. In terms of acceleration, supermaneuverability does not create any new stress that hasn't already been studied for physiological consequences. Linear acceleration amplitude and jolts are below the values generating serious physiological symptoms, such as blackouts or loss of consciousness. However, pilots can sometimes experience rotational acceleration that they are not used to, or combinations of accelerations they find unfamiliar. Psychologically, these accelerations can have two different consequences:

- Psychophysiological consequences due to the way information is perceived (i.e., trouble with perception), and the generation of sensory illusions and disorientation. These aspects developed in the previous chapter.
- Psychomotor and cognitive consequences.

The psychomotor and cognitive consequences of linear acceleration have not been studied in depth yet. A review of the available literature shows that most of the work is centered on the loss of consciousness under +Gz acceleration: description of psychological symptoms leading to loss of consciousness and return of intellectual capacities after a loss of consciousness (2). For our purpose, the consequences on vision for medium intensity accelerations (3–5G), which are well known to pilots need to be noted: progressive reduction of field of vision, progressive loss of colored vision, drop in visual acuity, and the ultimate symptom, total blackout. These are all symptoms, which can directly alter the pilot's capacity of capturing information. The visual consequences of –Gz accelerations are also well known in the pilot community: a decrease in perceptual capacities, and negative scotoma in the visual field.

On the motor side, heaviness in head and limbs, associated to the difficulty of moving them, must be taken into account in all motor activities to be performed by the pilot, especially since these motor tasks can be further degraded because of the stress induced by the equipment worn.

Little work has been done on the effects on psychomotor and cognitive activities at acceleration rates that are lower than the thresholds associated with loss of consciousness. Brown and Lechner's survey (3) insists that acceleration has a negative impact on simple motor activities, complex activities (putting on a parachute) and cognitive processes (reaction time in choice making, time required to stabilize the aircraft after loss of control, etc.). But, as noted by the authors, there are few experiments and little data is available to check the real effects acceleration has on the various steps involved in information processing. Hendler's work, quoted by Forster and Cammarota (4) is interesting for maneuverability. It shows that performance during a tracking psychomotor task decreases as the time during which acceleration is applied increases. These authors conclude by saying that the change in acceleration level is more disabling to the performance of a psychomotor task than the acceleration level actually applied. Albery (5), aware of the fact that cockpit tasks are becoming increasingly cognitive in military aircraft, carried out a survey aimed at assessing workload during acceleration. Using Subjective Workload Assessment Technique, mental workloads during cognitive tasks performed in a centrifuge significantly increased acceleration plateaus (1,4G, 2,75G and 3,75G). This study is one of the few investigating the cognitive consequences of accelerations, but, as mentioned by the author, it is limited by the assessment method, which is global and hardly analyzes the underlying cognitive processes. In practice, such studies have strong methodology limitations for the generalization of results to real flight. The tasks easily accomplished in the centrifuge (target tracking, choice reaction time, etc.) to assess cognitive performance have a poor ecological validity for flying and real mission tasks. Albery and Chelette (6), in an experiment examining the effect of G-suits on cognitive performance, pointed out these limitations and encouraged the use of more realistic tasks.

For +Gx accelerations, the available data in the literature involves high acceleration values, greater than 5G (2). Symptoms include limited head and limbs mobility and loss of peripheral vision. Starting at 7G, a psychomotor decrease is described, without any further detail. Effects of Gy acceleration are better known. It mainly generates problems of head support and limb mobility.

Effects of rotational acceleration on performance have also not been studied in depth (2). The main results describe diminution of psychomotor performance with high acceleration. Applying acceleration across time is also associated with human effects. The majority of the research addressing rotational acceleration, either alone or in combination with other accelerations, has focused on the effect of sensory illusions and disorientation.

3.3. Implications for supermaneuverability

What bearing can this have, in terms of supermaneuverability? The psychological consequences of low and medium intensity accelerations have hardly been studied. The few available studies tend to show that psychomotor and cognitive capacities decrease under acceleration, without any details as to the nature of the degradation. On the other hand, these results were obtained with acceleration profiles different from those usually encountered in supermaneuverability. Caution is therefore required when generalizing the above mentioned results.

These two remarks illustrate the need to develop specific work in order to better grasp what psychological effects low and medium intensity accelerations may have. Such research should take into account the specifics of supermaneuverability, including acceleration combinations for which there is no available data. Investigating cognitive functions requires developing methodologies going beyond mere global performance analysis. These methodologies need to measure the changes in mechanisms involved in perception, analysis, understanding, decision-making and risk taking. Furthermore, in addition to analyzing the consequences which may be observed during the execution of specific maneuvers, it seems important to also take into account the tiredness or fatigue which may occur when such maneuvers are repeated several times during a single mission. Physical and psychological fatigues are closely linked, and the fact that fatigue alters human reasoning capabilities is well known (7). These recommendations underline how important it is to take operational realities into account in designing any research on this topic.

From a practical point of view, the lack of data requires investigation into what actually happens in squadrons. Despite the new stress of supermaneuverability, the pilots reported that they are not experiencing any increase in psychologically disabling stresses over that already occurring in non-supermaneuverable aircraft. Today, pilots report they empirically manage psychological consequences. Relying on their experience, pilots develop management, anticipation or avoidance strategies, which help them carry out their tasks. When faced with supermaneuverability, this acquired experience will probably be used to transfer strategies or adapt new ones. However, from a preventive point of view, the only way to develop effective management techniques is to have a better knowledge of psychological consequences.

4. COGNITIVE CONSTRAINTS

4.1. Questionnaire results

Close combat with modern aircraft generates numerous cognitive constraints. Pilots mentioned both the constraints generated by aircraft capacities and those generated by systems capacities. For 65% of the pilots, these constraints are experienced as increased workload, but this feeling is not shared by all. This difference of opinion depends on what systems and interfaces are on-board, because they can make situation management more or less convenient. Analyzing the various cognitive constraints shows that:

- Time pressure is seen as the lowest constraint. This judgment seems strange, given the very short response time available to manage situations. In fact, responses are supposed to be so quick that time is not available for management purposes. Rather, responses must be reflexive. Thinking is considered a waste of time. The pilot "feels" rather than "understands" what is going on; assessing trends and reacting according to experience.

- Loss of information was rated a slightly higher constraint than time pressure, without being truly penalizing since it often has no consequence on the immediate time frame. The information lost usually involves non-priority issues. It is unusual to lose track of high priority items, since the pilot's attention is totally focused on them. However, when priority information is lost, situational awareness seriously deteriorates and consequences on performance can be far-reaching.

- The complexity of the information supplied by on-board systems or by outside communication media represents a severe constraint for crews. Information complexity raises the issue of human/machine relationships, and of the phrase "the right information at the right time in the right format." With today's systems, the crew has a better grasp of its environment. But the information provided has been pre-processed and is not always compatible with the crew's immediate mental representations. There is a gap between an equipment manufacturer's design rationale and the crew's logic of employment. This complexity is further compounded by the lack of transparency surrounding the way the data were obtained and the processing applied to it. Weapons systems are becoming increasingly sophisticated and even though their implementation is facilitated by aids, using them presents a significant mental load for the crew.

- Information flows also constitute a strong constraint. These flows result from the increasing number of sensors and communication networks. They open up the pilot's "field of perception", but on the other hand also flood the aircrew with a mass of information difficult to handle given the lack of information management systems.

- The strongest constraint is the quick pace at which situation change. This is directly linked to the maneuverability of agile aircraft. Visual contact with other aircraft is an absolute priority to manage engagement and combat. Aircraft aerodynamic capabilities make it almost impossible to predict flight trajectories, and it becomes increasingly easy to suddenly have a turnaround in a given situation, and lose an advantage, which had previously been acquired. The extension of flight envelopes multiplies tactical opportunities and makes anticipation more and more difficult. Anything can happen faster than ever, and the situation changes rapidly. Agility helps achieve unexpected moves, which can surprise an opponent, but can also at any time lead to losing the upper hand. Combat is fought in a more demanding spatial and dynamic environment, requiring greater mental effort (often done subconsciously during combat) to observe, predict, fly and fight.

4.2. A frame to describe cognitive constraints of agile aircraft

In order to extend these results to agile aircraft, a frame to identify and describe cognitive constraints is required. Aeronautical situations are complex. But what does complexity actually mean, and how can a situation be described in connection with its complexity? The complexity of a situation involves several dimensions (8):

- The task characteristics,
- The knowledge required to complete the task, and
- The difficulty experienced by the pilot to implement the required knowledge in order to fulfill task goals.

Orasanu (9) describes a complex situation as a situation characterized by:

- Ill-structured problems,
- An uncertain and dynamic environment,
- Shifting, ill-defined, or competing goals,
- Action/feedback loops,
- Time stress,
- High stakes,
- Multiple players, and
- Organizational goals and norms.

These characteristics can all be found in aeronautical situations. The following question remains: is the complexity of air-to-air combat involving agile aircraft identical to the same combat situation with non-agile aircraft, and if not, what makes it different, and what consequences may this have on pilots? To answer these questions, it is necessary to look into the various elements of complexity.

4.3. The task characteristics

The task and its characteristics are commonly referred to as complexity factors. They are description elements external to pilots, and help compare the complexity of various situations. Several categories of factors can be used to describe the complexity of a given task.

4.3.1. Time factors

Task dynamics

Task dynamics are defined by the average length of time taken by the various steps in a task, and by the transition speed between steps. Combat tasks are eminently dynamic tasks. With agile aircraft, dynamics are increased during specific flight phases (attack and escape maneuvers), and during some sequences of systems use (arming or countermeasure systems). Increased task dynamics reduce the possibility of reversing actions performed by pilots, thus also reducing the possibility of detecting or correcting errors made.

Time pressure

Time pressure is the time available to understand, decide, and take action. It is a deadline. With agile aircraft, it seems that some flight phases and systems involve more time pressure than air-to-air combat schemes with traditional aircraft. For the pilot, an increase in time pressure means less time to analyze, alternative solutions envisaged before making a decision, and assess the consequences of these decisions for the medium and long terms. Time pressure is a factor, which increases pilot workload and stress.

Time references

Pilot activity is organized around three time references (10):

- Physical time, i.e. the time frame used to keep track of developments in threat and environment. It is the time given by the clock.
- Systems time, i.e. non-compressible time units, which represent the operating or transition time of aircraft or on-board systems. For example, to execute a "post-stall" maneuver, aircraft aerodynamics requires an amount of time over which the pilot has no power. Another example: the transition time it takes to go from one weapon mode to another cannot be faster than what is required by the system. Systems time is important, because it is forced upon the pilot. The pilot must organize its activity around it.
- "Pilot" time is a kind of internal clock, specific to the pilot. It is the perception by the pilot of time passing by. This feeling is very different from physical time. Everyone knows that when you are bored, time is very long, whereas when you are busy, time flies. In aeronautics, pilot time is developed by experience; it is structured around memorized time sequences. It helps in adapting to changes in the environment and knowing: (i) when to take action, (ii) when control is possible, and (iii) when reasoning is possible.

The pilot lives with the continual difficulty of simultaneously managing these three time frames. With more and more automated and computerized systems in agile aircraft, systems time is an increasing constraint on the pilot. Successful combat requires systems time to coincide with clock time, which means having a proper time-based mental picture of the way systems operate, and of the way the environment changes.

Schedule of relevant information

Flying an aircraft is a task where information continuously flows in. Some information has an immediate relevance to the task, the moment it is perceived by the pilot. It is then integrated into the task underway. Other information has no specific value at the moment it is perceived by the pilot. However, it may be of value later on during further task developments, or may never be of any use (11). Managing the schedule of relevant information is an important factor of complexity in aeronautics, because unexpected situations are part and parcel of tasks performed. It is therefore difficult to know ahead of time what information will be of value during the mission. Since pilot memorization capacities are limited, pilot cannot remember everything. However, managing the schedule of relevant information does not seem to be more of a challenge with agile aircraft than in more traditional combat situations.

4.3.2. Task dimensionality

This term represents all the paths available to the pilot to reach the goal involved in the task. By creating new operational possibilities, agility multiplies the pilot's possibilities of action: more maneuvers are possible, which can all be coupled to different systems use. Each solution has its pros and cons, which the pilot must be aware of. Compounding this with time pressure, it becomes difficult to comprehensively assess all the available alternatives. Preference-based behavior often appears, favoring a solution readily "in mind", rather than one which would be ideally appropriate for the situation.

4.3.3. Multiplicity of goals

Air combat is a task which may be broken down into sub-tasks, each having specific goals. Managing goals, or giving priority to specific sub-tasks, is not always easy, especially since sometimes some goals compete with each other. For example, in air-to-air combat, success and security can be contradictory, in terms of the choices made by the pilot. Agility introduces nothing new in the management of goals than what is observed in more traditional air-to-air combat situations.

4.3.4. Risk-linked factors

Moving around in four dimensions generates risks. In air combat, this risk is very high, because it is linked to the scope of possible aircraft movements and to the presence of one or more hostile elements, over which the pilot has no power. Amalberti (8) makes a distinction between two kinds of risks: objective external risks, illustrating the probability of having an accident, or failing the mission, and subjective internal risks, specific to the pilot, and representing its fear of not knowing how to perform, of not having the situation under control. In agility, the first risk depends on the operational capacities of hostile elements. But the second risk may be increasing, since the pilot might find it more difficult than usual to assess the situation and obtain satisfactory situational awareness. Risk is another element increasing workload and stress.

4.3.5. Multiple players and organizational norms

These factors have no agility-related specificity in close combat except the choice between one-seat or two-seat agile aircraft. Now, agile aircraft are one-seat aircraft. In order to identify the role of this factor, a question on the possibility of adding a second crewmember (pilot or Weapon System Officer) to help relieve situation complexity was included in the questionnaire. Pilots had different opinions on this, since:

- 52% believed a second crewmember would not improve performance, and could even deteriorate it. They argued that the time constraint involved in the situation does not leave enough time for an effective dialogue. Perception-action cycles are too short to allow for real coordination.

- 38% believed this could help, allowing task sharing and providing relief in highly strained psychological situations (four eyes are better than two). The cockpit should however then be designed to accommodate task sharing. Collective work rules also need to be developed to offer the best synergy possible. Some pilots see a second crewmember as a useful operator, not necessarily in combat situations, but in order to ensure aircraft survivability, should the pilot lose situational awareness.

- Finally, 10% had mixed feelings; they believed a second crewmember would add effectiveness, but remained very doubtful as to the feasibility of such a cockpit and on the definition of really effective collective work rules.

4.3.6. Factors specific to systems and their design

Aids systems on current modern aircraft

On current modern aircraft, questionnaire responses indicate that close combat is not possible without aid systems. The physical and cognitive constraints described by pilots are so demanding that the pilot alone will find it difficult to handle the complexity of the situations encountered.

Modern aircraft are equipped with a great number of different systems designed to aid pilots. As a rule, pilots are quite satisfied with them. The small number of criticisms related more to the systems interface than functionalities. When pilots were asked what additional aids they would like to have, they mention technical systems. However, the main point raised in their answers is that it is important to ensure that the functionality and operability of the systems are complementary, with efficient, pilot-centered interfaces. However this is not easy to achieve, given the extent to which technology and human factors research have addressed human performance in complex systems. The shortcomings mentioned by pilots involved limitations in these two areas, which will obviously require further research works.

Aids on board modern aircraft (see also Pilot-Vehicle Interface Chapter) can be grouped into two categories:

- Aids providing relief for part of the pilot's activity, even if final control is required,

- Aids helping the pilot perceive and understand the situation to make better decisions and to carry out programmed actions.

Among the aids providing relief in various pilot activities, are the following:

- Navigation and flying aids,

- Protection systems management,

- Electric Flight Control System: they free the pilot from various flying constraints, but must be "care free" to be optimum. "Care free handling" system is a system that integrates flight and propulsion control, and enables a limited number of controls (stick and throttle) to be used to maneuver the aircraft inside the whole flight envelope and takes care automatically of the aircraft limitations.

Among the aids enhancing information processing:

- Improved sensor performance: radar, optronics, Identification Friend or Foe, and low ground clearance alarm systems all provide improved information on the environment.

- Displays: HMD/HMS, 3-D audio, wide field-of-view HUD. The purpose of these displays is to minimize pilot head movement for retrieving information during combat phases, and help maintain watch outside of the cockpit (acquiring visual items, and never losing track of them).

- Voice or data transmission communication media to obtain information known by the system or by people outside the cockpit.

- Information presentation more in line with the pilots' cognitive needs: analog rather than digital displays, presentation of aircraft energy state, integration of information from various sources on a same medium, and preliminary processing of data displaying safe and dangerous zones.

- HOTAS concept for facilitating control of multiple systems while reducing reaction time and maintaining the hands on the throttle and on the stick.

- Direct voice input for hands-free control.

Challenges for implementing aids systems in agile aircraft

Behind current aid systems advantages and limitations, some questions due to cockpit automation and computerization raise and have consequence on cognitive constraints. Aid systems define the conditions under which pilots are required to complete tasks. On-board systems are more and more computerized. Automation has invaded the cockpit to increase performance. The basic flying tasks can be totally performed by systems (e.g. piloting, navigating). For other tasks (e.g. weapons, countermeasure management), systems partially support the pilot (see also Pilot-Vehicle Interface Chapter). Besides assisting the pilot, automation can cause problems. For instance, if the pilot only manages systems and does not directly pilot the aircraft, the pilot's flying ability can deteriorate and be inadequate should the automatic system fail. Moreover, automated systems can misrepresent a situation or provide erroneous data when they are not programmed correctly. Woods and al (12) expounded at length on these factors in the framework of human error, and spoke about "a clumsy use of computer technology". Since sufficient information on systems equipping future agile aircraft is still lacking. It is impossible to fully explore "systems ergonomics." However, it is possible to identify several factors which will increase the complexity of the pilot's task onboard agile aircraft:

- Systems logic. Systems operate according to mathematical and physics logic and do not always follow operational procedures, or use logic. This can result in additional complexity for the pilot, as the system's rationale, or the way the system arrived at the solution may not be obvious (13). "Transparency" of systems is often mentioned. For the pilot, this means, on the one hand, an increase in workload to understand or verify the way the system operates, and on the other hand, a confidence in the system (which is only relative, because its logic is sometimes "surprising"). Automation is likely to increase in agile aircraft to help the pilot handle task dynamics and time pressure and keep the pilot's workload compatible with mental capacities.

- Multiplicity of information. Agility can only be envisaged with aircraft equipped with an ever increasing number of sensors, along with communication networks, which integrate all the aircraft in a fleet and the command and control systems. This information comes in addition to the data already available in the cockpit, to update aircraft and system status. The pilot is confronted with multiple pieces of information that are difficult to manage. The pilots especially found this a problem in the various screens displaying tactical situations. However, some data on weapons status, countermeasure management and aggressive hostile capacities are absolutely necessary. There are several kinds of pilot aids possible: more widespread use of the various sensory channels with multimodality displays, and the pre-processing of data either by an assistant or human operator. Designing such aids is a challenge, and represents an open field of research for human factors. The consequence of this multiplicity of information is the risk of inadequate situational awareness with the potential of erroneous decision making.

- Multiplicity of controls. In parallel with the multiplicity of information, many new controls have appeared in cockpits with multi-role combat aircraft. The number of controls has considerably increased to use the different systems for both air-to-air and air-to-ground missions. For instance, Switches are more numerous, closer together, and often incorporated as a multifunction control, whereby the function of the switch changes, depending on the flight phase. The increasing complexity of the dialogue between the pilot and the systems increases the risks of making mistakes or of forgetting something, especially since pilot workload and stress are also on the increase.

- Access to information. Multifunction displays are also more prevalent because it is impossible to simultaneously display all the information pertaining to the environment, aircraft, and systems. With the hierarchical organization of information, the displayed page may not correspond to the current functional needs of pilots. Moreover to access data on a different page, the pilot has to remember where the information is stored and have the time to perform the steps (usually button presses) to retrieve the desired information. These requirements are not always compatible with the task. To try to minimize workload, careful design of the dialogue is needed and the provision needs to be made for the pilot to pre-select desired functions, based on anticipated requirements in an upcoming complex flight phase. The display location in the cockpit is also import to relate to the current mission phase. Information needs to be displayed in the most convenient location for the pilot's current task. Any conflict between head-up and head-down displays for information retrieval could decrease pilot performance.

- Feedback. Information feedback is a factor which Sarter and Woods (11) consider as essential for situational awareness. Feedback makes it possible to stay inside the control loop to make sure the desired goal is reached after the implementation of appropriate actions. It also makes it possible to detect errors made, and therefore to possibly remedy them. Another kind of feedback, just as important for the pilot, is the feedback provided by systems when they automatically change modes (e.g., when automatic pilot id engaged or during automatic changes of weapon system state during a delivery sequence). Feedback is also necessary on the state and potential possibilities of systems. There again, feedback allows the pilot to stay inside the monitoring loop, and to maintain adequate situational awareness. Feedback on the aircraft aerodynamics is especially important for agility management because many of the typical sensations are no longer available with integrated digital flight control systems.

4.4. Knowledge required to execute a task

These factors involve the qualification of agile aircraft mission personnel. The qualification level is determined by psychomotor and cognitive abilities required of the pilot to successfully carry out missions. The identification and definition of these abilities is accomplished by analyzing tasks and pilot activity. Pilots can obtain the required abilities in two different ways:

- Through training, be it theoretical, by simulation, or in real life situations,
- Using existing pilot experience.

Now, it is difficult to accurately determine the psychomotor and cognitive abilities required to successfully carry out missions with agile aircraft. However questionnaire responses give pilots opinions on this topic. The questionnaire was aimed at assessing two items:

- Physiological and psychological abilities required by aircrew to fly modern aircraft in situations of close combat,
- Specific training developed for these crewmembers.

According to the pilots' answers, it seems that a good physical condition is essential. This fitness must be supplemented by regular acceleration training in centrifuges and in real life situations.

The psychological qualities of competent combat aircrew listed were: aggressiveness, willpower, enthusiasm, ingenuity and cunning. Pilots mentioned various cognitive abilities: good spatial capacities, excellent eye-to-hand coordination, quick reaction time, and efficient information management. The comments also stressed that pilots need to be reactive, flexible, accurate, cautious (knowing importance of verification), and able to make decisions under stress.

Beyond these abilities, strictness and professionalism were considered as the two essential qualities of a good fighter pilot. These two qualities help pilots know their aircraft and its systems inside out, as well as enemy aircraft. Knowing all these automated and computerized systems is extremely time-consuming given the great number of available functions, and implementation options, and sometimes the difficulty encountered by the pilots to totally understand the functioning of these systems. The qualities of a fighter pilot must be developed by training, in simulators as well as in flight. "Full-scale" mission simulators are essential to acquire this know-how, but cannot replace practice in real life conditions. This practice must be regular and frequent, because the abilities developed are complex and require permanent reinforcement. The final goal of this training and practice is to make pilot's behavior automatic so they can react as quickly as possible any given situation and its constraints.

4.5. Difficulty experienced by the pilot

Task difficulty is subjective feeling, specific to each pilot. The more difficult the task is felt to be, the more the pilot will assess it as being complex. Difficulty can also be thought of as the outcome that reflects a person's experience, knowledge, and ability to manage situations and fulfill task goals (8). The pilot's performance results from the interaction between the situation, acquired expertise and stress level, "difficulty" being the way the pilot experiences this interaction. Performance is guided by the overwhelming concern to save cognitive resources, i.e. not to exceed their limits, and also the need to keep some in store to maintain a margin for adaptation (14).

In addition, stress generated by the mission stakes effects the way the pilot processes information. Cognitive effects of stress are well known and have to be taken into account to assess the pilot's performance. They include: reduced thinking, "tunnel vision", excessive hurry, mental regression, "act at any cost" and mental block (15). Knowledge of these stress effects is important for training pilots and designing stress-resistant interfaces.

Fatigue is also an important factor to define the way the mission is difficult for the pilot. Mental and physical fatigue is closely linked in combat mission where physical and mental requirements are high. Fatigue has several effects on information processing mechanisms. Perception, memory, attention, understanding, decision making, risk making and action accuracy may be decreased (7)

In the framework of agile aircraft, it is difficult to know ahead of time how difficult things will be for the pilot. It will depend on aircraft ergonomics, pilot experience and, pilot's stress and fatigue states. But it is obvious these factors need to be taken into account in the design agile aircraft man-machine interface.

5. SITUATIONAL AWARENESS AND HUMAN PERFORMANCE

In order to cope with agile aircraft, pilots also need to be "agile". Human agility can be defined like the cognitive mechanism helping pilots answer questions on the status of the situation at hand. It also helps them make choices in order to reach the goals they set for themselves. During air-to-air close combat, pilots have to answer many questions:

- Where am I?
- Where am I going?
- Where are the enemies?
- Where are the enemies going?
- Where are friendly aircraft?
- Where are friendly aircraft going?
- What is the aircraft's energy status
- What is the status of on-board systems?
- What is my weapon delivery envelope?

The pilot will make the choices it feels are best adapted to meet the objectives, after integrating the answers to all these questions. It could seem that these questions contribute towards developing a solution that guarantees successful pilot performance. However, the reality is that in real world missions:

- The pilot has limited perception, memorization, information processing and action capacities,
- All the information is not available,
- Some information is uncertain,
- Other information is there, but difficult to perceive and understand,
- The situation changes rapidly, and unexpected or unknown events may occur, and
- The aircraft and its systems have their own limitations.

Despite all this, the pilot must face the situation, and develop cognitive strategies. Believing that the challenge of pilot performance lies within these strategies, the human factors community has decided to study them, and to address two specific aspects: situational awareness and decision making.

5.1. How to define situational awareness?

Vogel (16) mentions that the term "situational awareness" was used in United State Air Force pilot manuals even before being defined. The "situational awareness" notion being absolutely crucial to mission success, human factors specialists have looked into it, to offer a definition and to assess and describe what mechanisms come into play to build up and maintain situational awareness.

First distinction is necessary between situational awareness and spatial orientation. As Menu and Amalberti point out (17), spatial orientation is the capacity to position oneself in relation to a given fixed reference, represented by the horizontal and vertical directions in space. Situational awareness is the capacity to position oneself in relation to a relative reference system made up of the dynamic properties of the objects located in the geographical and tactical environment. Spatial orientation is a mechanism underlying situational awareness.

The literature provides two different approaches to research on situational awareness (18):

- One approach deals with the components of situational awareness. It is a "product" centered approach. One of the most comprehensive definition comes from Wickens (19): "situational awareness is a continuous extraction of environmental information about a system or environment, the integration with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception, anticipating and responding to future events". Through this definition, Wickens underlines that:

a) situational awareness does not just involve perception, but also integrates understanding and anticipation (20),

b) there is situational awareness of environment as well as of the aircraft and its systems,

c) situational awareness not only helps to anticipate, but also to appropriately react to situations.

- The second approach studies the mechanisms by which cognitive resources are managed and adapted so the pilot can form a understandable and coherent mental picture representing the situation, continually updated with recurrent situation evaluations (11). This is a "process" centered approach, which stresses:

a) the interdependence and non-linearity of memory, perception and action (18),

b) the importance of time awareness and feedback (11), and

c) the link between situational awareness, decision making and action (21).

The description of situational awareness properties and mechanisms helps to better understand the difficulties, which may be encountered in flying agile aircraft. Upon entry into a combat situation, the key challenge to pilots is how best the update their situational awareness:

- On the one hand, situational awareness needs to be sufficiently valid in time to avoid not being able to act and having to allocate all resources available into merely updating situational awareness,

- On the other hand, the pilot must be able to continuously integrate information, to update situational awareness and avoid working with mis-adapted situational awareness.

The answers to this conflict depend on the abilities of pilots to operate at various levels of understanding (22). For some situations, an abstract or "big picture" awareness is adequate, minimizing cognitive demands. The details to which situational awareness is updated can also vary, depending on the time and other resources available. Also, the pilot may decide to only attend to updating aspects that are critical to the situation. For example, in an air-to-air combat phase, having only a rough picture, or no picture at all, of the state of the inertial navigational system has no disabling effect on the ability of the pilot to engage in combat.

5.2. Agility and situational awareness

Situational awareness is defined by pilots as having sufficient perception and understanding to be able to predict future changes occurring in the situation, from the information supplied by the outside, on-board systems and links connecting the aircraft with the outside. For pilots, situational awareness in a close combat situation involving modern aircraft is a major issue. In the survey, 78% of the 29 pilots surveyed said they had sometimes lost situational awareness during these flight phases.

The physiological and psychological constraints mentioned above influence the situational awareness developed by pilots. In addition to just having situational awareness, pilots also raise the question of having the right situational awareness. Is it necessary to have total situational awareness, or is partial awareness sometimes sufficient? The realities of air combat show that when engaging in combat, situational awareness needs to be as comprehensive as possible. However, once combat is engaged, the predictability of the situation changes and the time constraints, information flows, and lack of critical information (such as identification of external link targets) make it difficult if not impossible, for pilots to acquire comprehensive situational awareness. It can only be partial, and can range from high to low. The difficulty is then for the pilot to assess the relevance of this partial awareness to the situation, decide whether it is sufficient or not, and decide to continue the combat or stop. In practice, under specific situational awareness threshold, combat should be stopped, but in real life things are never this simple. This is a very important issue for pilots.

The questionnaire also tried to identify whether different components of situational awareness are easy or not to acquire and maintain in modern air combat. According to the pilots' answers, it seems that:

- Knowledge of the energy situation of modern agile friend or foe aircraft is more difficult to acquire and maintain than in older combat circumstances. Pilots explain this by referring to the frequent and rapid changes occurring in the physical and tactical environment. It is no longer easy to assess and predict the speed, banking rate, altitude, and potential acceleration of enemy aircraft. In regards to the pilot's own aircraft, several factors contribute to this decreased perception of the aircraft's energy situation. For instance, the information displayed in the cockpit is often illegible or difficult to access. Also electronic flight control systems minimize the feeling and other feedback cues on the aerodynamic state that were available with older flight control systems.
- Identifying the envelope for weapon delivery and knowing the present and future position and trajectory of friend or foe aircraft are also more difficult to accomplish than in former combat situations. This opinion also shows that despite the increasing number and sophistication of on-board systems, the information supplied to pilots does not greatly contribute to enhancing situational awareness in highly complex combat environments. The pilots did not directly mention root causes. However, one reason may be that the nature of the information displayed and/or the way it is displayed does not meet pilots' cognitive requirements.
- On future aircraft, pilots do not envisage to acquire good situational awareness without high level of automation for support systems and man-machine interfaces This feeling reflects the constant efforts made by designers. A great number of on-board systems are now perceived as being essential and crucial to achieve the mission. However, pilots mentioned the functional coherence between systems functions, aids, aircraft properties and interfaces do not always exist. Future aircraft design has to be users' need-centered and not a technology "patchwork".

Regarding human agility, pilots need to be able to maintain adequate situational awareness, while optimizing resource allocation. However, in reality, one or more of the following are plausible for agile aircraft flight:

- Pilot has inadequate situational awareness due to the lack of information or because the knowledge required is not available,
- Pilot retains and outdated situation representation, because it does not have the resources necessary to change it,
- Pilot adopts too abstract of a representation leading to imprecise situation management,
- Pilot is not aware that its situational awareness is outdated. Captain Peeples (23) of United States Air Force talks about an "ultimate situational awareness" to describe a pilot's capacity of being aware that he does not have an adequate situational awareness.

5.3. Decision-making

Decision-making has been extensively studied in aeronautics. At first, research work was carried out within normative approaches, trying to define an optimal decision making model. The work of Jensen (24) on Aeronautical Decision Making models must be mentioned. Extensively used to train pilots on decision-making, these models quickly proved their shortcomings, when trying to explain how pilots made decisions. Under Klein's lead (21), a new approach to the modeling of the mechanisms involved in decision making, in real work situations, was developed: Naturalistic Decision Making. These studies, like recent studies on situational awareness, belong to the research movement focused on "situated" cognition.

Decision-making is not simply an algorithmic process analyzing all possible hypotheses to choose the best one. A decision is a cognitive mechanism constrained by the task at hand and the pilot's expertise. Klein's recognition-primed decision model (21) suggests the following:

- The more complex the constraints in a situation, the more decision strategies will be based on situation recognition, and not on analytical processes.
- Recognition of the situation generates an option, which then undergoes evaluation. If the option is deemed not valid or feasible, the pilot carries out a diagnosis to generate a new solution, and so forth. This is a serial process of option evaluation.
- If the situation is a familiar one, actions are carried out without further evaluation.
- The main difference between experienced pilots and more junior ones is not that the former have better reasoning, but that they have a better capacity at having a mental picture of the situation.
- The more expert the pilot, the quicker the situation will be recognized.
- The pilot is more likely to choose and execute an option that it is familiar with. In other words, the right decision is the decision the pilot knows how to implement.

Performance is the result of pilot behavior. It involves tactical aspects (shooting the enemy or flying away) as well as mission safety aspects (managing separation with other aircraft, managing aircraft movements in relation to ground or to ground-air threats). The complexity of close combat makes the simultaneous and comprehensive management of all these goals difficult. Pilots have to prioritize issues, and set a number of activities aside. Another solution is to simplify operations by lowering control precision, and only using familiar routines or a portion of the functions or capabilities of each system.

The higher the constraint, the more the pilot will operate sequentially, processing one single goal after another. Goal prioritization then becomes a key element in mission success. Of course in the background, the pilot must also stay on the lookout to detect any alarm signal, which could challenge the priority list established. The difficulties entailed by goal management are especially noticeable when managing the energy situation of the aircraft, acquiring and maintaining contact with enemy aircraft, and using the weapon systems. Yet, the closer the target, the more dynamic and unpredictable the situation becomes, ever decreasing the time available to perceive, understand, and act. Conversely, a pilot must be able to use the aircraft's movement potential and systems changes to surprise the enemy. Tactics are now less predictable than before and their implementation is increasingly reactive.

The impact for pilots stems from the level the pilot is in control over the situation. The pilot is in control when there is enough capacity to anticipate situation developments. Loss of control results in a reactive behavior. The pilot no longer controls events, but becomes subject to them, and is always trying to catch up with the aircraft. In modern close combat, tactical patterns are more numerous and more diverse, given the increased options allowed by aircraft maneuverability and by weapons system performance. The pilot cannot anticipate all possible tactics, but even if this was possible, it would require an in-depth knowledge of the possibilities offered by enemy aircraft and systems. Because of this, some pilots say that although modern aircraft have a higher performance level than older ones for close combat, they require the adoption of an increasingly opportunistic behavior since it is very difficult to anticipate situation developments and the pilot is less and less frequently in control of the situation.

The questionnaire answers also stated that agility cannot only be envisaged in terms of aircraft maneuvering capacities. In addition to airframe agility, systems and weapons agility must also be taken into account. Agility is the capacity to minimize the time required to acquire and shoot an enemy and systems and weapons play a role as important as the airframe itself. The agile aircraft must be a coherent entity, within which the "intellectual" agility of the pilot is integrated.

In conclusion, the demands of agile aircraft missions will further constrain decision making in numerous ways:

- There may be insufficient time to generate more than one or two options, making it more critical that these few options are appropriate for the situation;
- The situation can change very rapidly, making the assessment of options more difficult;
- Consequently, there is increased likelihood that options, will be executed that have not undergone preliminary evaluation;
- Given the agility of the airframe and weapons, it is more difficult to develop a three-dimensional picture of the situation and perform mental simulation of candidate options.

Having a better understanding of decision-making mechanisms makes it possible to envisage what could be done to enhance decision making. Beyond decision making aid or assistance systems, a very important aspect is to help pilots retain a greater number of previously evaluated tactics in their memory. This could help pilots react faster when there are insufficient resources to assess options in real time.

However, There is also a danger in allowing reasoning to be so rigid that it allows options to be executed without full evaluation as to whether they are appropriate. This mechanism is found in routine errors or “slips”, as mentioned by Norman (25). Thus, additional techniques that can facilitate "agile decision making" are needed that enable pilots, while taking into account the ongoing dynamics of multiple aspects of a situation, are able to arrive and execute timely solutions which culminate in mission success.

6. CONCLUSION

The experience acquired on last generation combat aircraft and on "supermaneuverable" aircraft prototypes can be used to predict the consequences these concepts will possibly have on pilots' intellectual capacities and on information processing mechanisms.

Existing data show that the decrease in psychomotor capacities occurs mainly during changes in acceleration rates, and that there is an overall reduction in information processing capacities when the pilot passes through acceleration plateaus (perception, understanding, decision making). However, these results were obtained with experimental protocols having little in common with the acceleration profiles encountered in supermaneuverable aircraft. Thus, they must only be considered as a basis on which to conduct more specific research work. This research, in a first phase, should quantitatively and qualitatively assess the effects of accelerations on psychomotor and cognitive capacities, and in a second phase, assess these same capacities in the framework of supermaneuverability. The effects of acceleration on psychological capacities are not well known, but it is important to realize that pilots already experience these effects in traditional aircraft, and have probably learned to manage them, without any further formalization. There is no reason for the psychological consequences of supermaneuverability to be more serious than those already experienced in traditional aircraft. Of course, a better knowledge of this stress could help pilots develop better management techniques (training), and could help the design of adapted aids.

Superagility refers to the human/aircraft relationship, in view of reaching a goal. Beyond the mere agility of the airframe and its systems, human agility needs to be taken into account. Human agility results from information processing mechanisms, which lead to situational awareness and decision making. Analyzing the complexity linked to agility helps identify the various factors involved, and envisage the consequences they may have on information processing. The effects of these factors are analyzed through a "situated" approach of pilots at work, where pilot performance results from the interaction between the situation and pilot's expertise and within which the pilot manages cognitive compromises. Agility does not create new psychological constraints for the pilot, at least as such. But it amplifies the constraints already existing in aeronautical situations. With agility, the pilot will find it increasingly difficult to manage cognitive compromises, and will tend to use information processing strategies, which increase the risk of mistakes or mis-adapted choices. The in-depth study of these mechanisms will help develop new training schemes for pilots, innovate systems and interface design, and provide assistance to pilots.

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ANNEXE 1

SITUATIONAL AWARENESS QUESTIONNAIRE FOR AGILE AIRCRAFT PILOTS

1- Background

Current assigned aircraft type:

Assigned aircraft hours:

Total flying hours:

Flying hours on agile aircraft: What type?

Age:

2- During close-in combat with agile aircraft, what are the main constraints to manage to have a good situational awareness?

3- In comparison with current fighter aircraft, are the following items more or less difficult to acquire with agile aircraft?

	more difficult	**no difference**	**less difficult**
Where I am?			
Where am I going?			
Where are enemies?			
Where are enemies going?			
Where are friendly aircraft?			
Where are friendly aircraft going?			
Knowledge of aircraft energy status?			
Knowledge of weapon delivery envelope?			

Comments to explain your responses:

4- Are there Gz and Gy accelerations constraints to maintaining situational awareness during close-in combat with agile aircraft? Could you explain your response?

5- Are there Gz and Gy accelerations constraints to handling the man-aircraft interface commands during close-in combat with agile aircraft? Could you explain your response?

6- Close-in air-to-air combat is a complex dynamic situation. Among the items characterising a complex situation, which are relevant for close-in air-to-air combat with agile aircraft?

	no relevance	**relevant**	**very relevant**
Time pressure			
Sudden changes			
Sudden loss of information			
More complex information			
Increased information flow			

Comments to explain your responses:

7- Have you lost situational awareness during close-in air-to-air combat with agile aircraft?

If yes, could you explain the circumstances?

8- Do you think that anticipating tactics during close-in air-to-air combat is more problematic with agile aircraft?

Could you explain your response?

9- Do you think your mental effort is increased fighting with agile aircraft?

Could you explain your response?

10- Do you have the feeling that if you lost situational awareness with an agile aircraft, it is more difficult to retrieve it in comparison with current fighter aircraft?

Could you explain your response?

11- Have you already been surprised by the behaviour of agile aircraft during close-in air-to-air combat?

Could you explain your response?

12- Which support systems might improve situational awareness during close-in air-to-air combat with agile aircraft? (for instance: helmet mounted display, head down display with tactical situation, 3-dimensional auditory, pilot's assistant, etc.). Could you justify your responses?

13- Do you think a second pilot or a weapon system officer would be useful in the agile aircraft to have better situational awareness and effectiveness?

Could you explain your response?

14- For you, what are the skills to be an effective agile aircraft pilot?

15- To train future agile aircraft pilots, what changes would be useful to introduce in the pilots' training courses?

16- If you have other comments on the human consequences of agile aircraft, you can explain them below:

We thank you for your co-operation